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Original Research Paper

An optimization model for improving highway safety

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ABSTRACT

This paper developed a traffic safety management system (TSMS) for improving safety on county paved roads in Wyoming. TSMS is a strategic and systematic process to improve safety of roadway network. When funding is limited, it is important to identify the best combination of safety improvement projects to provide the most benefits to society in terms of crash reduction. The factors included in the proposed optimization model are annual safety budget, roadway inventory, roadway functional classification, historical crashes, safety improvement countermeasures, cost and crash reduction factors (CRFs) associated with safety improvement countermeasures, and average daily traffics (ADTs). This paper demonstrated how the proposed model can identify the best combination of safety improvement projects to maximize the safety benefits in terms of reducing overall crash frequency. Although the proposed methodology was implemented on the county paved road network of Wyoming, it could be easily modified for potential implementation on the Wyoming state highway system. Other states can also benefit by implementing a similar program within their jurisdictions.

1. Introduction

In 2014, there were 14,699 total crashes in the state of Wyoming, including 131 fatal, 2818 injury, and 11,750 property damage only (PDO) crashes (WYDOT, 2015b). The monetary loss associated with these crashes is approximately $550 million. In the state of Wyoming, there are a total of 27,831 miles of roadway owned and maintained by federal, state, and local entities (WYDOT, 2008). Although most states have their own traffic safety management system (TSMS), Wyoming does not have TSMS yet (Mishra et al., 2015). This research study focuses on developing a TSMS for county paved roads.

In Wyoming, there are 2444 miles of county paved roads (approximately 8.8% of total) (WYDOT, 2015a). The Wyoming Technology Transfer Center (WYT^2/LTAP) is in the process of developing a pavement management system (PMS) for these

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county roads. As part of that effort, a comprehensive data collection program was conducted by the WYT^2/LTAP and WYDOT in the summer of 2014. That effort expanded to the safety area and included developing a TSMS since some of the data collected for PMS can be used for developing TSMS. The collected PMS data included road identification information, traffic data, roadway width, rut depths, international roughness index (IRI), pavement condition index (PCI), and pavement serviceability index (PSI) (WYDOT, 2015a). Some of this information was instrumental in developing the model for TSMS.

Many Wyoming county roads were built over 40 years ago and had inconsistent maintenance, resulting in overall poor road conditions (Saha and Ksaibati, 2015). Moreover, the growth of oil and gas industries has increased truck traffic on county roads. The increase in truck traffic resulted in significant economic loss due to crashes which necessitates the development of an innovative TSMS to utilize limited resources more efficiently.

The developed methodology will ensure that selected safety projects will minimize the number of crashes especially the fatal-and-injury crashes within preset budgets. In the proposed methodology, selecting safety improvements does not only depend on traffic volumes but also on the crash reduction factor (CRF) of the countermeasures. A CRF is a crash reduction percentage that might be expected after implementing a countermeasure at a specific hot spot. Safety improvements will be selected based on the highest level of crash number reduction. There are 917 county paved roads with total length of 2444 miles in Wyoming. This study utilized all these roads to demonstrate the implementation of the proposed optimization model.

2. Literature review

The literature review which summarizes recent research on TSMS can be divided into three sections which are safety performance function (SPF), crash hot spots, and optimization methodology for safety management system.

2.1. *Safety performance function*

In order to improve safety, it is important to understand why crashes occur. There is a significant number of researches modeled crash occurrence (Abdel-Aty and Radwan, 2000; Ahmed et al., 2011; Cafiso et al., 2010; Chin and Quddus, 2003; Jovanis and Chang, 1986; Miaou and Lord, 2012; Tegge et al., 2010). Abdel-Aty and Radwan (2000) studied the modeling of traffic accident occurrence and involvement. The results showed that annual average daily traffic (AADT), speed, lane width, number of lanes, land-use, shoulder width, and median width have statistically significant impact on crash occurrence. Tegge et al. (2010) studied SPFs in Illinois and found that AADT, access control, land-use, shoulder type, shoulder width, international roughness index, number of lanes, lane width, rut depth, median type, surface type, number of intersections have a significant impact on safety. Cafiso et al. (2010) developed comprehensive accident models for two-lane rural highways and found that section length, traffic volume, driveway density, roadside hazard rating, curvature ratio, and number of speed differentials higher than 10 km/h increased crash occurrences significantly. Highway safety manual (HSM) provides the safety performance functions for the roadways divided into rural two-lane two-way roads, rural multilane highways, and urban and suburban arterials (AASHTO, 2010). The safety performance functions provide the predicted total crash frequency for roadway segment base conditions. More accurate predicted crash frequency can be measured considering the CRFs from the geometric design and traffic control features.

Researchers have utilized different approaches to establish the relationship among crash occurrences, geometric characteristics, and traffic related explanatory variables using statistical models of multiple linear regression, Poisson regression, Zero-Inflated Poisson (ZIP) regression, Negative Binomial (NB) regression, and Zero-Inflated Negative Binomial (ZINB) regression. In 1986, Jovanis and Chang (1986) studied why multiple linear regression is not appropriate for modeling crash occurrence since accident frequency data did not fit well with the basic assumptions underlying the model. The major assumption with linear regression models is that the frequency distribution of observations must be normally distributed. Most crash frequency data violates this assumption. It was also observed that crash frequency data possesses special characteristics such as count data and overdispersion. In 1993, Miaou and Lord (2012) studied on the performance evaluation of Poisson and Negative Binomial regression models in modeling the relationship between truck accidents and geometric design of road sections. This research recommended that the Poisson regression or ZIP model could be the initial model for relationship establishing because of the crash frequencies. But in most crash data, the mean value of accident frequencies is lower than the variance, which is termed as overdispersion (Saha et al., 2015). If overdispersion is present in crash frequency data, NB or ZINB would be appropriate models since they account for overdispersion. In most accident data, crash frequencies show significant overdispersion and exhibit excess zeroes, in which the ZINB regression model appears to be the best model.

2.2. *Crash hot spots*

There are 12 crash hot spot analysis techniques discussed in HSM (AASHTO, 2010). These techniques basically rank the sites with potential safety issues. The criteria for raking the sites are based on average crash frequency, crash rate, relative severity index, critical crash rate, level of service of safety, and predicted crash frequency. Some states have their own identification methods in addition to the 12 HSM crash hot spot analysis techniques. Moreover, a significant amount of researches have been performed to identify crash hot spots using different identification methodologies and screening methods such as sliding scale analysis, empirical Bayesian (EB) method, Kernel density estimation (KDE), Moran's I Index method and Getis-Ord Gi* (Anderson, 2009; Cheng and Washington, 2008; Elvik, 2008; ESRI, 2010; Getis and Ord, 1992; Hauer et al., 2004; Montella, 2010; Persuad et al., 1999; Saha,